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FULL LENGTH ARTICLE

Formula of definite point overburden pressure of reservoir layers

M. Karimi [a,*], M.R. Adelzadeh [b], M. Mohammadypour [c]

[a] *National Iranian South Oil Company, Reservoir Research Centre, Iran*
[b] *National Iranian South Oil Company, Petroleum Engineering, Iran*
[c] *National Iranian South Oil Company, Scientific and Research Affairs Centre, Iran*

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Abstract Overburden pressure, P_{ob}, is pressure imposed on layers during the different hydrocarbonic layers operations by the weight of overburden layers. Practically, the geological layers structure varies in matrix and porous media during well head treatment operations such as acidizing, hydraulic fracturing and fluid injection when drilling and completion. So, three structural quantity inter-granular space (IGS), inter-fracture space (IFS) and fracture width (FW) affect fluid conductivity and layers P_{ob} alternations.

Using the petrophysic and geological information and the content of tables under the reservoir conditions, P_{ob} was formulated for a drilled layer point in various porosity ranges.

Since reservoir layers mostly have heterogeneity characterizations, and timely and repeatedly need to control the type of cutting lithology, drilling mud and reservoir pressure by geologists and drillers, the equations derived are effective in wellhead and bottom hole operations for the calculations in which the overburden pressure plays a key role.

1. Introduction

The classified parameters in three tables of inter-granular distance (IGS), inter-fracture space (IFS) and fracture width (FW) have been defined for the reservoir layers which have endured the pressure of upper layers. These structural parameters are applicable in other equations in acidizing, stimulation, and drilling in other references. Classifications are designed based on a total survey on the various characteristics of reservoir cuttings and core samples through macroscopic and microscopic methods, in which are utilized the characteristics such as the size and situation of particles, color, the percent of clay, qualitative and quantitative examination of porosity and permeability, the property of consolidating and un-consolidating layers with static and dynamic tests in the laboratory and wellhead using tin sections and whole plugs in different sectional areas, and as well as other servicing companies reports. On the other hand, the effect of viscosity that has been related empirically and experimentally to the overburden pressure by the density of fluids, time, and weight of fluids engaged can approach/highlight the properties between

* Corresponding author.
E-mail address: karimioilm@gmail.com (M. Karimi).

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Nomenclature

Physical quantities

ρ	density
V	volume
V_b	bulk volume
V_p	pore volume
W	weight
L	length
h	depth of desired point or layer to the surface
A	sectional area of layer
A_w	sectional area of well
g	acceleration of gravity
T	temperature
μ	viscosity
P	pressure
φ	porosity
S	saturation
S_o	oil saturation
S_w	water saturation
d_1	inter-granular space
d_2	inter-fracture space
d_3	width fracture

Subscripts

r	rock
b	bulk
d	dry
w	water
o	oil
ob	overburden pressure

Numbers

A	for conversion Kgf to bar

Functions, etc

μ_O	oil viscosity equation
P_{ob}	overburden pressure equation in a point of depth

fluid and rock in the basement. The model is easy enough to code up for software applications making its widespread use on injective and oil layers. The proposed formula is derived in the framework of the fluid displacement process in the laboratory and geological elements in field dimensions, and is applicable in reservoir engineering, reservoir geology and geophysics.

Porosity, mineral composition, inter-granular elastic behavior, and fluid properties are primary factors. These factors are dependent upon overburden pressure, fluid pressure, microcracks, age, and depth of burial [16,24,26,28,30]. Any variation of the density will affect the weight of the overlying water and, consequently, will affect the pressure that acts on a given horizontal surface. Formation pressures are vital to the safe planning of a well. Accurate values of formation pressures are used to design safe mud weights to overcome fracturing the formation and preventing well kicks [13,4,5,25]. Reduction of sediment porosity and increase in density of layers under overburden pressure in the sea floor are important subjects in earth sciences. Data and samples from the deep Sea drilling Project allow a new look at these subjects, and are used to establish profiles of laboratory values of density and porosity versus depth in the sea floor [2,12–14,21]. The dynamic displacement experiments studied the effect of the confining pressure on porosity and absolute permeability. These experiments were conducted on small, consolidated rock samples under overburden pressure up to 6000 psig and a room temperature of 23 °C. The pore pressure was maintained at atmospheric conditions. The examination of experimental results shows a decrease in porosity and permeability with an increase in overburden pressure [11,20,22,23]. In references above, the role of porosity, density, load of fluid, fluid volume, effect of temperature and pressure, depth and types of sedimentary on the overburden pressure of a layer and geological structures are clearly observed. In general, all previous findings have been focused on the overburden pressure of a special point with different parameters under ambient conditions [1,3,6–11,14,15].

Before beginning the overburden pressure equations of oil wells in this paper, at first some of the primary methods used to calculate overburden pressure are enumerated in Eqs. (1–5) as follows:

The overburden pressure at a depth z (for a continuously stratified fluid) which is a function of parameters z, P_0 and g is given by

$$P(z) = P_0 + g\int_0^z \rho(z)dz \qquad (1)$$

$\rho(z)$ is the density of the overlying rock at depth z and g is the acceleration due to gravity. P_0 is the datum pressure, like the pressure at the surface. Equation implies that gravitational acceleration is a constant over z since it is placed outside of the integral. Strictly speaking, for almost all boundary conditions, g should appear inside the integrand since g is a function of the distance from mass. However, since g varies little over depths which are a very small fraction of the Earth's radius, it is placed outside of the integral in practice for most near-surface applications which require an assessment of lithostatic pressure. In deep-earth geophysics/geodynamics, gravitational acceleration varies significantly over depth, demanding that g be taken, at least, as a function of depth [17].

The hydrostatic pressure is the weight of the fluid column per unit of area at a depth Z. Fluid in this condition is known as hydrostatic fluid. The hydrostatic pressure can be determined from a control volume analysis of an infinitesimally small cube of fluid [13]. Since pressure is defined as the force exerted on a test area ($P = F/A$, with p: pressure, F: force normal to area A, A: area), and the only force acting on any such small cube of fluid is the weight of the fluid column above it, hydrostatic pressure can be calculated according to the following formula:

$$p(z) = \frac{1}{A}\int_{z_0}^{z} dz' \int\int_A dx'dy'\rho(z')g(z') = \int_{z_0}^{z} dz'\rho(z')g(z') \qquad (2)$$

p is the hydrostatic pressure (Pa). ρ is the fluid density (kg/m^3), g is gravitational acceleration (m/s^2), A is the test area (m^2), z is the height (parallel to the direction of gravity) of the test area (m), z_0 is the height of the zero reference point of the pressure (m).

For water and other liquids, this integral can be simplified significantly for many practical applications, based on the following two assumptions: Since many liquids can be considered incompressible, a reasonably good estimation can be made from assuming a constant density throughout the liquid [12,27,31]. Also, since the height h of the fluid column between z and z_0 is often reasonably small compared to the radius of the Earth, one can neglect the variation of g. Under these circumstances, the integral boils down to the simple formula:

$$P = \rho g h \tag{3}$$

where h is the height, $z - z_0$ is the liquid column between the test volume and the zero reference point of the pressure. Note that this reference point should lie at or below the surface of the liquid. Otherwise, one has to split the integral into two (or more) terms with the constants ρ_{liquid} and the $\rho(z')_{\text{above}}$. For example, the absolute pressure compared to vacuum is:

$$P = \rho g h + P_{\text{atm}} \tag{4}$$

where h is the total height of the liquid column above the test area at the surface, and p_{atm} is the atmospheric pressure, i.e., the pressure calculated from the remaining integral over the air column from the liquid surface to infinity. This expression states that, at any depth, the pressure will simply be given by the atmospheric pressure plus the weight of the water above the desirable depth. Another useful equation for calculating the overburden gradient under field conditions of varying lithological and pore fluid densities (this formula can calculate the pressure in every depth) has been derived below [29].

$$\sigma_{\text{ovg}} = 0.433[(1 - \varphi)\rho_{\text{ma}} + (\rho_{\text{f}}\varphi)] \tag{5}$$

σ_{ovg} = overburden gradient, psi/ft. φ = porosity expressed as a fraction. ρ_{ma} = formation fluid density, gr/cc.

2. Basic and quantitative classification tables to obtain inter-granular space, inter-fracture space and fracture width in reservoir layers [18,19]

The basic investigation is organized on three important reservoir layer parameters that treat the analysis of fractures and the distances of the fractures and grains depending on the size and situation of grains using experimental, macroscopic and microscopic information. So, the well-site geologist and driller should communicate on a chosen target point, especially when looking for lithology changes so as to become aware of programs of casing, drilling formation, mud circulation and logging. Therefore, most of the reservoir characteristics to distinguish and recognize the lithology type so as to reach to the aforementioned tables can be provided at the wellhead and down-hole before, during, and after drilling or logging related operations, at least over any zones of interest. Though these tables might change slightly up or down for a desired point of the reservoir layer, especially as a nonnative agent is seen in the composition and nature of main layer, as a rule of thumb, those are generally accepted. So, whatever tables are decided upon, those tables should cover all interpretations and reports in so far as they do not imperil the certainty of results. In locations containing faults, space size may create restrictions in the use of tables, thence a geologist should while drilling distinguish one layer from the other layers in a ‘‘quick look’’. In a fault-bearing area the matrix grains position has a more weak role exclusively on limit of large fracture gaps and latitude and longitude, the equations mentioned earlier are no longer applicable, therefore it necessitates that we usually easily apply the same to the simple relationship of Eq. (3) and to other fracture pressure gradients. If a pressure discrepancy is seen in these major gaps, from both a high pressure amount and an operational standpoint or costly seismic wave-related surveys hazards, the reason should be examined so as to focus on the data sets of through-casing logs, mud type, density, viscosity, pH, temperature, fluid loss, and other on-site observations in the rig-up and running times in the target area. This information must coincide with the wellhead and laboratory report.

All the lithology examinations have been related to the probable pressures in the underground layers in which the most important reservoir aspects such as permeability and porosity that are considered in these examinations that have been grouped in 7 or 8 groups. There are three major reservoir lithology types of sandstone, limestone and shale/clay which might be observed either separately or mixed with each other. These major reservoir lithologies may contain non-native particles, therefore the sample cuttings containing fractures, microcracks, and grained type in these lithologies can then be further examined in the laboratory so that the type of non-native lithology can be determined, matching it with classification tables. This grouping is one of the easiest and least problematic methods to include the effect of distance of fractures and grains in significant reservoir parameters. Results in grouping are sensitive to variations in coarse size, fine-grain size and fracture, as well as the porosity and permeability properties in the matrix media. In general, all the concepts of the investigation that have mostly been linked with observations in field scale, imply how the grain size, course-or minute-fractures, and pressure or stress vary in various lithologies under certain conditions.

So, the grain size in the limestone porous media is decreased causing a decrease in the distance of grains in a range less than that of sands. To interpret and estimate the lithology and petrophysical characteristics (to obtain the data of tables), has been used of wellhead macroscopic date and the outcome compared with the microscopic and experimental data at the laboratory. The macroscopic data are obtained based on a total survey on the various types of reservoir cuttings and core samples in which the characteristics such as the size and situation of particles, color, percent of clay, qualitative and quantitative examination of the porosity and permeability, and the consolidation and un-consolidation characteristics of layers with tests of static and dynamic at laboratory are determined using the tin sections and whole plugs in different sectional areas for different types of rocks in lithology. These three parameters are explained, respectively, in three tables below. In concepts and references of this investigation, the effect of the table’s results on the overburden pressure is explained. In Table 1 the inter-granular space (IGS) which is indicated as d_1, is estimated as that of the seven groups of rocky layers in which with increased clay fractions in the containing layer, the IGS is decreased. The biggest distance is observed in the coarse particles with the size of 0.05 m, as with an increase of clay percent from lowest value of the table, the size of grains is decreased. So, the weaker inter-granular consolidation (high IGS) has a lower effect in the growth of overburden pressure than in layers with more clay percent which are in the lower series of the table. Most of the reservoir layers have patches

Table 1 Estimation of reservoir rocks inter-granular space (IGS) or d_1 based on microscopic and macroscopic studies.

ID	Lithology	Inter-granular space, m
1	Coarse particles	5×10^{-2} to 10^{-2}
2	Fine sands	10^{-2} to 2.5×10^{-3}
3	Sand with limestone/dolomite	2.5×10^{-3} to 5.5×10^{-4}
4	Sand with limestone/dolomite/shale	5.5×10^{-4} to 6.5×10^{-5}
5	Limestone/dolomite	$6.5 \times 10^{-5}$to 7.5×10^{-6}
6	Shale sands	7.5×10^{-6} to 10^{-7}
7	Shale/clay	Less than 10^{-7}

of anhydrite in their containing layer, and if these layers consist of sand and/or coarse particles, then overburden pressure in these layers is increased. If two whole plug types of the pure sand and the sand which has small minerals such as limestone, clay and/or anhydrite, be compared together at the laboratory, then it is observed that the potential of solidity and overburden pressure in the pure sand with the high IGS is lower. Thereby, the IGS has a reverse ratio with overburden pressure and in layers with more inter-granular space (IGS), the overburden pressure confined to a point, is diminished. In Table 2 the inter-fracture space (IFS) is indicated with d_2 that is the same distance between two fractures which are apart from each other, and is also estimated with the seven groups of rocky layers which in the classification of IGS had been considered. The biggest distance is observed in coarse particles with a size of 0.025 m at which with increase of the clay percent from the lowest value of the table causes the decrease of the grain size, the IFS is diminished, as in the shale layer this percent is a minimum amount. Therefore, if the distance between two fractures apart from each other be enlarged, it means that the matrix media in this distance is expanded, and overburden pressure on the lower layers (down of table) is further off.

Both d_1 and d_2 are obtained on averaging the amounts given in related ranges to each rock in Tables 1 and 2. So, the effect of inter-granular space (d_1) and inter-fracture space (d_2) on the overburden pressure is observed in equations of overburden pressure at which (d_1) has a reverse ratio with P_{ob} and d_2 has a direct ratio with P_{ob}. In Table 3 the fracture width (FW) which is indicated with d_3, is the width of the fracture estimated for eight groups of rock lithology. In this classification, contrary to two classifications of IGS and IFS, the width fracture is diminished in the coarser particles. For example in a reservoir with components of limestone, the FW is much more. Therefore, the increase of FW in this classification has a reverse ratio to the overburden pressure and solidity of layers. Nevertheless, in classifications of IGS and IFS, the increase of IGS and the decrease of IFS had respectively, a reverse and direct ratio with overburden pressure. Note that

Table 2 Estimation of reservoir rocks inter-fracture space (IFS) based on microscopic and macroscopic studies.

ID	Lithology	Inter-fracture space, m
1	Coarse particles	2.5×10^{-2} to 10^{-2}
2	Fine sands	10^{-2} to 10^{-3}
3	Sand with limestone/dolomite	10^{-3} to 5.5×0^{-4}
4	Sand with limestone/dolomite/shale	5.5×10^{-4} to 10^{-5}
5	Limestone/dolomite	10^{-5} to 10^{-6}
6	Shale sands	10^{-6} to 10^{-7}
7	Shale/clay	Less than 10^{-7}

Table 3 Estimation of reservoir rock fracture width (FW), based on experimental, microscopic and macroscopic studies.

ID	Lithology	Fracture width, m
1	Coarse particles	Less than 10^{-7}
2	Coarse sands	10^{-6} to 10^{-7}
3	Fine sands	5.5×10^{-5} to 10^{-6}
4	Sand with limestone/dolomite	5.5×10^{-4} to 10^{-5}
5	Sand with limestone/dolomite/shale	10^{-4} to 10^{-5}
6	Shale sands	10^{-3} to 10^{-4}
7	Limestone/dolomite	10^{-2} to 10^{-3}
8	Shale/clay	More than 10^{-2}

d_{max} and d_{min} are maximum and minimum ranges of fracture width, and are shown in Table 3, finally, after substituting them in Relationship M in Eq. (9) (depending on the porosity range) we can calculate the d_3 of each lithology type. Fig. 1 shows a matrix media in which the situation of positioning two grains and two fractures is indicated as d_1 and d_2.

So, in the above classifications, we should have responded to the questions below:

1. The first question which may baffle many engineers is where to apply these classifications?
   As stated earlier, these classifications have helped in that the drilling or logging-related items can to be applied to evaluate the fracture pressure encountered within a well or at a certain point of the reservoir layer and make calculations relevant to the matrix structures.
2. How can we use these classifications to interpret and include the role of distances inter-granularly and at inter-fractures?
   We identify the lithology type, d_3 shown in Table 3 using relationship M in Eq. (9) (depending on the porosity range), and d_1 and d_2 on the averaging of two ranges maximum and minimum in the same lithology as shown in Tables 1 and 2.
3. How are IGS, IFS and FW obtained?
   Using the geological and petrophysical characteristics which we obtained in macroscopic information (the various correlation plots and logs) in the wellhead or microscopic in the laboratory, we can determine the IGS, IFS and FW. The criteria are met through supplementary coring or conventional methods that are used information at the desired depth which is always confirmed by the wellsite geologist, and pin-point where it is to be sampled.
4. What is the necessary information in classifications and where can we utilize these classifications?
   Information contain Porosity and permeability in qualitative and quantitative situations, cementing, color, compaction pressure, consolidating and un-consolidating property, particles size in lithology, density and distances of fractures and grains experimentally and empirically. Overburden pressure equations related to a defined point (DPOBP) in all depths are used but overburden pressure equations related to a defined layer (DLOBP) are used only in reservoir layers without faults. We intend to treat/drill the large-scale layer in which the nature of reservoir lithology and the presence of fluid will be discussed. Because faults have a wide range in size of their fracture, the information about

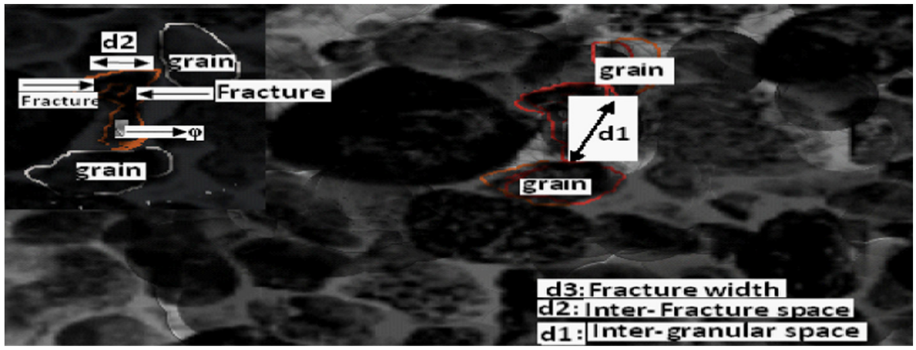

Figure 1 A completely sandy and porous layer with patches of anhydrite which developed a matrix media (space between fractures or grains).

faults needs extensive knowledge of geologic, laboratory measurements, well logs and seismic data to determine the fluid pressure within the faults. So, in faults in which macro-cracks can be regarded, the fracture width (d_3) might be very great than a fracture width in a common reservoir.

3. New formula to determine the overburden pressure in a definite point of oil layers

An efficient formula for obtaining the quantity of overburden pressure has been derived by using the experimental and field data. This formula is incorporated in the framework of the petrophysic and geologic samples and infinite elements based on the core flooding displacement experiments in the laboratory. These equations have been written for three sets of rocks as to Eqs. (6)–(8) and as well as two viscosities in Eqs. (10) and (11) as follows. Parameters inter-granular distance (d_1), inter-fracture space (d_2) and fracture width (d_3) have been given in Tables 1–3 in the text body. The results of these tables, in addition of this paper, have been applied in new equations to calculate the removed water block by mutual solvents in oil wells in other references.

$$P_{ob1} = \frac{1}{A}\left|\frac{C_1\rho_r ghA_w\sqrt{\left(\frac{\mu_o+\mu_w}{\mu_w}\right)}\sqrt{\frac{t_1}{t}}}{d_1^2}\right| + \frac{1}{A}\left|\frac{C_2(W_W+W_o)}{}\frac{1}{d_3^2}\right| = P_{ob1,1} + P_{ob1,2} \quad (6)$$

where: $C_1 = 2\times10^{-5}$; $C_2 = 0.02$; $d_3 = 100\%$ (0.1 M) $5 < \varphi \leqslant 15.5$.

$$P_{ob2} = \frac{1}{A}\left|\frac{C_1\rho_r ghA_w\sqrt{\left(\frac{\mu_o+\mu_w}{\mu_w}\right)}\sqrt{\frac{t_1}{t}}}{d_1^2}\right| + \frac{1}{A}\left|\frac{C_2(W_W+W_o)}{}\frac{1}{d_3^2}\right| = P_{ob2,1} + P_{ob2,2} \quad (7)$$

where: $C_1 = 1.75\times10^{-5}$; $C_2 = 0.04$; $d_3 = 50\%$(0.1 M) $15.5 < \varphi \leqslant 20.5$.

$$P_{ob3} = \frac{1}{A}\left|\frac{C_1\rho_r ghA_w\sqrt{\left(\frac{\mu_o+\mu_w}{\mu_w}\right)}\sqrt{\frac{t_1}{t}}}{d_1^2}\right| + \frac{1}{A}\left|\frac{C_2(W_W+W_o)}{}\frac{1}{d_3^2}\right| = P_{ob3,1} + P_{ob3,2} \quad (8)$$

where: $C_1 = 1.\ \ 5\times10^{-5}$; $C_2 = 0.06$; $d_3 = 30\%$(0.1 M) $20.5 < \varphi \leqslant 25$.

$$\text{In all equations } M \text{ is as to}: \ M = \frac{d_{max} - d_{min}}{d_{max}} \quad (9)$$

$$\text{If } T < 80\,^\circ\text{C then } \mu_o@T^\circ = \mu_0 - 22\text{PH}_o@60\,^\circ\text{F} \times \frac{(176^\circ - T^\circ)}{60\,^\circ\text{F}}[(\rho_o@15.5^\circ - \rho_o@T)/\rho_o@15.5^\circ] \text{ at which } \mu_0 = \mu_o@15.5\,^\circ\text{C} \quad (10)$$

$$\text{If } T \geq 80\,^\circ\text{C then } \mu_o@T^\circ = \mu_0 - 17\text{PH}_o@60\,^\circ\text{F} \times \frac{(T^\circ - 176^\circ)}{60\,^\circ\text{F}}[(\rho_o@15.5^\circ - \rho_o@T)/\rho_o@15.5^\circ] \text{ at which } \mu_0 = \mu_o@80\,^\circ\text{C} \quad (11)$$

P_{ob} is an overburden pressure on the bar. A = Constant of A is to convert the kgf unit to bar, and equals to 10197.162. φ = porosity, %. g = acceleration due to gravity. ρ_r = rock density, kg/m^3. ρ_w and ρ_o = oil and water density, kg/m^3. h = depth of layer from earth surface. $\rho_r = W_d/(V_{bulk} - V_{pore})$ at which V_b = bulk volume. A_w in m^2, sectional area of point drilled. V_p = empty spaces volume, W_d = dry weight, kgf. PH = oil acidity which is usually constant. t = geological age of favorite layer, million years (my), in which t_1 is the lower layer age. The constants of C_1, C_2 and C_3 are dimensionless numbers. T is reservoir or experiment condition temperature, F°. d_1 and d_2 are respectively, inter-granular space and inter-fracture space (matrix media or distance between fracture) on the meter. d_3 is fracture width on the meter. μ_w and μ_o are viscosity of water contact and oil in oil layer in reservoir temperature, and is expressed in kg/m-sec. d_{max} and d_{min} are maximum and minimum of fracture width, and shown in Table 3.

With attention to the subject matter of overburden pressure equations as mentioned earlier may raise the following questions.

1. How is overburden pressure (P_{ob}) calculated in a point defined?For a defined layer overburden pressure (DLOBP) can apply the questions 6 to 11 in reference [18]. But to calculate the set of pressures exerted of fluids and depth to the sectional area (A_w) of point drilled (SAODP) can apply the equations (6)–(11) in the text. So, the effect of time is decreased and approached to number 1 at the time when the target is a point in the vertical turn, and there is not a partial or quite horizontal treatment or turn. Moreover, the effect of inter-fracture (d_2) is also ignored because of the small size of the drilled point, but also the grains space (d_1) and fractures width (d_3) are taken into account.
2. What is the difference between P_{ob} in a point and hydrostatic pressure?In each of the two, to calculate of the hydrostatic pressure of water and other liquids, and pressure of layer column in a defined depth is applied from equations (3)–(5) from other authors (For e.g., fluid column in well) in which, hydrostatic pressure and layer column in a defined depth used the fluid and rock density, respectively, or equations aforementioned from (6)–(8) in which the amount calculated at the overburden pressure in a point is more. If we intend to calculate the P_{ob} within a fluid-saturated rock-mass and/or non-saturated, then equations derived from (6)–(8) are applied. So, equations (6)–(8) take into account the complete effect and the sensitivity of rock to fluid.
3. What are difference between P_{ob} in a point (POBP) and a defined layer (DLOBP) of under-ground?POBP implies an infinitesimal point, but in DLOBP, a layer with defined dimensions is considered. As that was said, in POBP is decreased the effect of geological age, space between two fracture and weight of fluids existence in layer related to point which is drilled, as the same hydrostatic pressure is considered [e.g., a layer in radius of 19 m and length of 80 m which has a $S_w = 20\%$ and $S_o = 80\%$, then whole fluids weight ($w_w + w_o = \rho_w g S_w \varphi V_b + \rho_o g S_o \varphi V_b$) is included in calculation of P_{ob}]. Afterward, in POBP the P_{ob} is calculated in a depth of the h for sectional area of A_w of well or point ($\rho_r g h A_w / d_1^2$) which is drilled. In DLOBP the effect of fluids weight on P_{ob} is similar to POBP, and because P_{ob} is in a greater dimension, the d_1 and d_2 relates directly to the fluids weight in the form given below.

$\left(\frac{(\rho_w g V_w + \rho_o g V_o)}{d_3^2}\frac{d_2}{d_1} = \text{Pressure} = P_{ob,n,2} \rightarrow n = 1,2,3\right)$ But weight the column of h on the defined layer is influenced by weight of defined layer (W_d) that are related together in the form given below.

$$\sqrt{W_d}\sqrt{\rho_r g}\frac{h\sqrt{d_2}}{d_1^2} = \sqrt{\rho_r g} \times \sqrt{\rho_r g V_d}\frac{h\sqrt{d_2}}{d_1^2} = \frac{\rho_r g h \sqrt{d_2}\sqrt{V_d}}{d_1^2}$$
$$= kg/m^3 \times m/s^2 \times m \times \frac{\sqrt{m \times m^3}}{m^2} = \frac{kg}{m \times s^2}$$
$$= pressure = P_{ob,n,1} \rightarrow n = 1,2,3$$

In DLOBP the effect of dry layer weight is separately related to the fracture width in the form $\left(\frac{\rho_r g V_d}{d_3^2} = \text{Pressure} = P_{ob,n,3}\right.$ $\left.\rightarrow n = 1,2,3\right)$.

Note that as above the ratio of $\frac{P_{ob,n,1}}{P_{ob,n,3}}$ has a linear relation with $\frac{h}{2r}$, at which h is the depth of the layer from the earth's surface and r is radius of the defined layer. So, $P_{ob,n,3}$ is a very small percent of $P_{ob,n,1}$ nearly under 2%.

4. When and where is the use of P_{ob} in a defined layer needed?We can apply the calculated pressure to calculate the important variations in injection and/or stimulation (refer to Ref. [9]), completion and drilling operations that have a large contact area in horizontal direction (e.g., types of injective layers, horizontal and directional wells).
5. What are the effects of increased pressure on the defined layer in underground operations?Once a layer in a defined size is treated and/or drilled with various operations (e.g. acidizing, stimulation, injection of fluid, and directional and horizontal drillings with high contact area), we can consider the effect of whole pressure on the solubility of injection liquids and fluids in situ.
6. How can we calculate P_{ob}?By incorporating and applying two sets of information in the field and laboratory according to the common methods at laboratories and Tables 1–3 and other geological and petrophysical characteristics we can estimate these equations.

4. Evaluation the physical overburden pressure quantities in a point of depth

4.1. Geological layer age

Repeatedly accumulation of sediments on the layers and passage oftime causes the related layer to undergo more overburden pressure. So, it should also be noted that the weight of the overlying sediments is subsequently affected by lithology changes, and consequently may change the load on these sediments with regard to the lower or upper sediments during the natural destructive variations. Under these conditions, old zone may move above the young zone causing more notably overburden pressure on the horizontal zones in the lower depths. Therefore t_1 and t are included in the formula (Note that t_1 is always the age of the desired layer in which its dimensions are already defined). It may be noted that the above equations imply that overburden pressure varies a little over geological layers time, as this pressure in shallow layers is a very small function of geological time (Equations of DLOBP is out of shallow layers limit). Once the age of upper layer is nearly the same as the lower layer, then because of better coherency and homogeneity, the pressure exerted on the lower layer is much more, as this reduction in calculation of P_{ob} in a defined point (DPOBP) is more than the defined layer (DLOBP).

4.2. Porosity (φ)

Porosity and lithology have been related empirically and experimentally to overburden pressure by the dry weight of the rocky layer and weights of water and oil. So, the formula can be written as analogous equations for the various reservoir layers with horizontal dimensions in three ranges of porosity. As is observed in equations, where the φ is decreased, the P_{ob} is increased, especially in dense rocks containing anhydrite patches.

Table 4 Example of overburden pressure of an oil layer with a length of 80 m at a depth of 3593 m.

Structural specifications the sub-layer of Asmari formation in Iran	Solution
Area section of layer (A), $m^2 = 1.13 \times 10^{+3}$; $A_{we} = 0.05\ m^{2;}$ $W_{d,kgf} = 203{,}8984$; h, m = 3593; ρ_w@60 °F = $1.145 \times 10^{+3}$; ρ_w@191 °F = $1.135 \times 10^{+3}$; ρ_o @60 °F = 851.9; ρ_o @191 °F = 821.9; ρ_r, kg/m^3 = $2.82 \times 10^{+3}$; φ, % = 18.86; K, md = 23; t, my = 25; t_1, my = 50; L, m = 80; μ_o@60 °F = 11.3; μ_o@176 °F = 3.3; μ_o@191 °F = 2.43; PH_O@60 °F = 6.8; μ_w@176 °F = 0.72; μ_w@ 60 °F = 1.73; μ_w@191 °F = 0.65 cp; $d_1 = 7.75 \times 10^4$; $d_2 = 5.5 \times 10^4$; V_w, m^3 = 3.37; V_o, m^3 = 13.49; V_d, m^3 = 73.78; (Densities unit are kg/m^3)	In Table 3 in ID of No. 4 have: d_3 = 50% (0.1 M) = 0.05 $(d_{max} - d_{min})/d_{max}$; $d_3^2 = [0.05\ (5.5 \times 10^{-5} - 10^{-5})/(5.5 \times 10^{-5})]^2 = 0.002$ m; $\mu_0@T = 191$ as to Eq. (11) equal to 2.43 cp. If substitute the data in Eq. (7), then P_{ob} in a point drilled to the defined radius equal: $P_{ob} = 9446 + 306 = 9752$ bar

4.3. Water, oil and rock density (ρ_w, $\rho_{o\ and}\ \rho_r$), depth from earth surface (h), inter-granular space (d_1) and inter-fracture space (d_2)

The densities and depth have a similar performance on the increase of P_{ob}. The influence of ρ_r is observed in $P_{ob1,1}$, $P_{ob2,1}$ and $P_{ob3,1}$ (each one of first segments in Eqs. (6)–(8) at which inter-granular space (d_1) has a reverse ratio with P_{ob}. While the d_2 or the same matrix media between two gaps and/or as well as between two fractures is more, the P_{ob} is higher and an inverse behavior occurs in contrast with d_1. Both d_1 and d_2 obtain on averaging the amounts given in related ranges at each layer (average of lower and upper limits in each lithology) in Tables 1 and 2.

4.4. Dry layer weight (W_d), oil (W_O) and water (W_W) weight and fracture width (d_3)

W_w and W_o refer to the pressure of ground water and oil held within a layer, in gaps between particles. In the underestimated layer of water and oil, the pressure is determined by W_d in $P_{ob,n,3}$ and is also referred to the effect of depth on the layer which is tested in $P_{ob,n,1}$. W_d is the dry weight of reservoir layer or rock sample which imposes a pressure on overburden strata. In non-sandy rocks or significantly sorted sands an increase of fracture width (d_3) and inter-granular space (d_2) in matrix and fractured media respectively, have an important role in decrease and increase of dry weight, as the P_{ob} is correspondingly low and high denoted as $P_{ob1,1}$ and $P_{ob1,3}$ in equations (6)–(8). Therefore, with attention to the table of d_3 the small measure of d_3 in porous rocks can have a significant increase on the P_{ob}. In non-sandy reservoirs or significantly sorted reservoirs which containanhydrite, the fracture width (d_3) is commonly more. Thus, the variation of d_3 is as to M in Eq. (9), at which the greatest percent belongs to the low porosity reservoirs that are mostly limestone and dolomite. So, in these low porosity reservoirs, the d_3^2 in the nominator of the fraction is increased, as a result the whole of fraction P_{ob} is decreased.

4.5. Viscosity, μ_o

Viscosity has been related empirically and experimentally to overburden pressure by the density of fluids. So, viscosity balance equation is most reliable when the rock contains one fluid under the reservoir conditions. The temperature is a very useful tool in the detection of changes in viscosity. The effect of temperature is taken into account by considering viscosity, density and fluid acidity properties.. So, a measure of the ability of the fluid to resist against the consolidation porous can be expressed in units of fluid velocity. The viscosity is a variable quantity in different temperatures, thus μ_o is calculated for different reservoir temperatures to share the role of salty water and oil in resistance of fluids on the contrary movement. The higher amounts of water density at temperature 60 °F illustrate a higher viscosity. The PH has usually a nearly constant amount in each oil layer which if increased causes adecrease in viscosity. In viscosity relationship, the higher amounts of oil density illustrate a higher viscosity at temperature 60 °F, and are a useful method in finding viscosity. (See Eqs. (10) and (11) for two ranges of temperature in which the unrequested mistake temperature (T° – 176F°) also has been corrected than reference [18]) Note that the μ_w is also obtained substituting the same information in equations μ_o.

5. Example

The objective of this example is to obtain the overburden pressure of reservoir layer (containing sand with a little dolomite and anhydrite) related to Pre-Miocene period (25 million years ago) which has been located on the layer with geological age of the Eocene period (50 my ago) as per data given in Table 4.

6. Results and discussion

The geological layer structure varies in matrix and porous media during the well head treatment operations such as acidizing, hydraulic fracturing and fluids injection at the time of drilling and completion. So, parameters such as inter-granular space (IGS), inter-fracture space (IFS) and fracture width (FW) are inter-granular and inter-fracture structural quantities are effective on the fluid conductivity, and overburden pressure brought about in the layers and the injected fluids and the in situ fluids.

In wells acidizing, stimulation and hydraulic fracture operations are necessary to estimate the situation of geometrical structure vicinity of the wellbore for types of reservoir lithology, thus the classifications d_1, d_2 and d_3 with other new variables composed in equations can calculate the precise overburden pressure in special points of reservoir layers.

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References

[1] A.E. Wren, Geophysics for Geologists; internal training course at Maxus Exploration Company, Cambridge University Press, 1993, pp. 70–120.
[2] A. Hurst, M. Huuse, J.A. Cartwright, D. Duranti, in: Atlas of Deep-Water Outcrops, Elsevier, New York, 2007.
[3] B. Lawn, Fracture of Brittle Solids, second ed., Cambridge University Press, Cambridge, 1993, pp. 300–378.
[4] C.E. Inglis, Trans. Inst. Naval Archit. 55 (1913) 219–241.
[5] D.V. Ellis, Well Logging for Earth Scientists, Elsevier, New York, 1987.
[6] D.J. Tearpock, R.E. Bischke, Applied Subsurface Geological Mapping, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1991.
[7] E. Eberhardt, B. Stimpson, D. Stead, Rock Mech. Rock Eng. Austria 32 (2) (1999) 81–99.
[8] F.K. Schlünz, Chem. Erde 10 (1935) 116–125.
[9] F.J. Pettijohn, P.E. Potter, R. Siever, Sand and Sandstone, second ed., Springer-Verlag, 1987, ISBN 0-387-96350-2.
[10] H. Blatt, G. Middleton, R. Murray, Origin of Sedimentary Rocks, Prentice-Hall Inc, Englewood Cliffs, New Jersey, 1980.
[11] H.S. Ali, M.A. Al-Marhoun, S.A. Abu-Khamsin, M.S. Celik, The effect of overburden pressure on relative permeability. Paper SPE 15730 presented at the Middle East Oil Show, Bahrain, March 7–10, 1987.
[12] H. Rabia, Well Engineering & Construction, Chapter 1, 1–70, USA, 0954108701, OTC, 2002.
[13] J.R. Jordan, O.J. Shirley, Application of drilling performance data to overpressure detection, JPT, 1966.
[14] J.R.L. Allen, Developments in Sedimentology, vol. 30, Elsevier, 1984, p. 593.
[15] J. Schieber, Sedimentology 36 (1989) 203–219.
[16] L.W. Gardner, G.H.F. Gardner, A.R. Grojery, Geophysics (New York) 36 (6) (1974) 770–780.
[17] M.K. Hubbert, W.W. Rubey, Role of fluid pressure in mechanics of overthrust faulting, Geological Society America, Bulletin 70, 1959, pp. 115–166.
[18] M. Karimi, M.R., Adelzadeh, in: GEOINDO, SP305, The International Conference on Geology, Geotechnology, and Mineral Resources (GEOINDO 2011), Thailand, December 1–3, 2011.
[19] M. Karimi, M.R. Adelzadeh, A. Helalizadeh, J. Petrol. Sci. Eng. 101 (2013) 68–74.
[20] Nasseri et al., in: ROCKENG09, Proceedings of the 3rd CANUS Rock Mechanics Symposium, Toronto, May 2009.
[21] R.R. Compton, Geology in the Field, John Wiley & Sons, New York, 1985.
[22] R. Muir-Wood, G.C.P. King, J. Geophys. Res. 98 (B12) (1993) 22035–22068.
[23] R.H. Sibson, in: J. Parnell (Ed.), Geofluids: Origin, Migration and Evolution of Fluids in Sedimentary Basins, Geological Society, London, Special Publications 78, 1994, pp. 69–84.
[24] R.H. Sibson, in: J.G. Buchanan, P.G. Buchanan (Eds.), Basin Inversion, Geological Society, London, Special Publications 88, 1995, pp. 3–19.
[25] R.H. Sibson, J. Geochem. Explor. 69–70 (2000) 471–475.
[26] T. Nltner, Submikroskopische Komponenten und Mikrotextur klastischer Sedimente, Doctoral Dissertation, University of Karlsruhe, Germany, 1988, p. 170.
[27] T.H. Nilsen, R.D. Shaw, G.S. Steffans, J.R.J. Studlick, AAPG Studies in Geology 56, CD-Rom, Elsevier, New York, 2007, 24p.
[28] W.F. Brace, Penn. State Univ. Mineral Exp. Stat. Bull. 76 (1961) 99–103.
[29] W. Matthews, J. Kelly, Oil Gas J. 65 (7) (1967) 92–106.
[30] W. Lowrie, Fundamentals of Geophysics, Cambridge University Press, New York, 1997.
[31] Wikipedia, http://en.Wikipedia.org/wiki/Overburden pressure at a depth, May 2009.